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PATENT

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Title of Invention: **TACTILE INPUT SYSTEM**

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Provisional Patent Application

TACTILE INPUT SYSTEM

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Field of the Invention

This document concerns an invention relating generally to man-machine interfaces for providing sensory feedback to users from electromechanical systems, and more specifically to tactile input systems.

Background of the Invention

Tactile input systems deliver information to the brain via the sense of touch, and are used for sensory substitution and augmentation. Prior tactile input systems used two-dimensional arrays of stimulators placed on a surface of the body, and delivering electrical or mechanical (motion) outputs to the user's skin, so that input signals (e.g., from a camera or microphone) were delivered to the user's skin as "patterns" of electrical or vibrational stimulus felt by the user's skin. The systems thereby supplement the user's sense of vision or hearing by providing tactile sensory input which is dependent on visual or audible inputs; in essence, the visual or audible sensory input is transformed to an analogous tactile input. As examples, *Bach-y-Rita et al.* (Vision substitution by tactile image projection, Nature, 221:963-4 (1969)) describe a system for augmenting or replacing vision by providing visual input through a 400-point vibrotactile stimulator array placed against the skin of the back. As noted in U.S. Patent 6,430,450, which describes a tongue-placed array of electrotactile stimulators, fingertip-scanned and abdominal stimulator arrays are also known.

As summarized in U.S. Patent 6,430,450, tactile input systems have several limitations. Many of these spring from the number and density of stimulators. Fewer

large stimulators naturally provide a "coarser" degree of informational input than the use of many small stimulators situated across the same area of the user's skin. However, it is difficult to reduce the size of the stimulators without encountering problems with their interconnection, and problems with the achievement of practical output amplitudes (i.e., electrical or mechanical stimulation signals which are suitably large that they can be accurately felt by a user). Thus, as of the year 2003, most systems have been limited to the use of stimulators having a density of 1.75 mm or so, which is approximately the spacing used between adjacent Braille dots.

Summary of the Invention

The invention is directed to tactile input systems which reduce or eliminate many of the problems encountered in prior systems by providing stimulators which are implanted beneath the epidermis, thereby allowing substantial size reduction of the stimulators because their output is closer to the nerves of the skin and is no longer "muffled" by the epidermis. Such size reduction allows higher stimulator densities to be achieved. Additionally, interconnectivity problems, and the issues inherent in providing input signals from an external camera, microphone, or other input device to an internal/subdermal stimulator (i.e., the need to provide leads extending below the skin), may be avoided by providing one or more transmitters outside the body, and preferably adjacent the area of the skin where the stimulator(s) are embedded, which wirelessly provide the input signals to the embedded stimulator(s).

Further advantages, features, and objects of the invention will be apparent from the following detailed description of the invention in conjunction with the associated drawings.

Brief Description of the Drawings

FIG. 1 is a simplified perspective view of an exemplary input system wherein an array of transmitters **104** magnetically actuates motion of a corresponding array of stimulators **100** implanted below the skin **102**.

FIG. 2 is a simplified cross-sectional side view of a stimulator **200** of a second exemplary input system, wherein the stimulator **200** delivers motion output to a user via a deformable diaphragm **212**.

FIG. 3 is a simplified circuit diagram showing exemplary components suitable for use in the stimulator **200** of **FIG. 2**.

Detailed Description of Preferred Versions of the Invention

A description of several exemplary versions of the invention follows. In all versions, it should be understood that the implantable stimulator(s) are preferably implanted in the dermis, the skin layer below the epidermis (the outer layer of skin which is constantly replaced) and above the subcutaneous layer (the layer of cells, primarily fat cells, above the muscles and bones, also sometimes referred to as the hypodermis). Most tactile nerve cells are situated in the dermis, though some are also located in the subcutaneous layer. Therefore, by situating a stimulator in the dermis, the stimulator is not subject to the insulating effects of the epidermis, and more direct input to the tactile nerve cells is possible. Perceptible tactile mechanical (motion) inputs may result from stimulator motion on the order of as little as 1 micrometer, whereas above-the-skin tactile input systems require significantly greater inputs to be perceivable (with sensitivity also depending where on the body the system is located). If the stimulators use electrical stimulation in addition to or instead of mechanical (i.e., motion) stimulation, a problem encountered with prior electrotactile systems – that of maintaining adequate conductivity – is also reduced, since the tissue path between the stimulators and the tactile nerve cells is short and generally conductive. Additionally, so long as a stimulator is appropriately

encased in a biocompatible material, expulsion of the stimulator from the skin is unlikely. In this respect, it is noted that when tattoos are applied to skin, ink particles (sized on the micrometer scale) are driven about 1/8 inch into the skin (more specifically the dermis), where they remain for many years (and are visible through the translucent, and often nearly transparent, epidermis). In contrast, implantation in the epidermis would cause eventual expulsion, since the epidermis is constantly replaced.

A first exemplary version of the device, as depicted in **FIG. 1**, involves the implantation of one or more stimulators **100** formed of magnetic material in an array below the skin (with the external surface of the epidermis being depicted by the surface **102**), and with the array extending across the area which is to receive the tactile stimulation (e.g., on the abdomen, back, thigh, or other area). Several transmitters **104** are then fixed in an array by a connecting web **106** made of fabric or some other flexible material capable of closely fitting above the skin **102** in contour-fitting fashion (with the web **106** being shown above the surface of the skin **102** in **FIG. 1** for sake of clarity). The transmitters **104** are each capable of emitting a signal (i.e., a magnetic field) which, when emitted, causes its adjacent embedded stimulator **100** to move. The transmitters **104** may simply take the form of small coils, or may take more complex forms, e.g., forms resembling read/write heads on standard magnetic media data recorders, which are capable of emitting highly focused magnetic beams sufficiently far below the surface **102** to cause the stimulators **100** to move. Thus, when an input signal is applied to a transmitter **104**, it is transformed into a signal causing the motion of a corresponding stimulator **100**, which is then felt by surrounding nerves and transmitted to the user's brain.

The input signals provided to the transmitters **104** may be generated from camera or microphone data which is subjected to processing (by a computer, ASIC, or other suitable processor) to convert it into desired signals for transmission by the transmitters **104**. (Neither the processor, nor the leads to the transmitters **104**, are shown in **FIG. 1**

for sake of clarity.) While the signals transmitted by the transmitters **104** could be simple binary on-off signals or gradually varying signals (in which case the user might feel the signals as a step or slow variation in pressure), it is expected that oscillating signals which cause each of the stimulators **100** to oscillate at a desired frequency and amplitude might allow a user to learn to interpret more complex informational inputs – for example, inputs reflecting the content of visual data, which has shape, distance, color, and other characteristics.

The stimulators **100** may take a variety of forms and sizes. As examples, in one form, they might simply be magnetic spheres or discs, preferably on the order of 2 mm in diameter or less; in another form, they might simply take the form of magnetic particles having a major dimension preferably sized 0.2 mm or less, and which can be implanted in much the same manner as ink particles in tattooing procedures. The stimulators **100** may themselves be magnetized, and may be implanted so their magnetic poles interact with the fields emitted by the transmitters **104** to provide greater variation in motion amplitudes.

It should be understood that each transmitter **104** might communicate signals to more than one stimulator **100**, for example, a very dense array of stimulators **100** might be used with a coarse array of transmitters **104**, and with each transmitter **104** in effect communicating with a subarray of several stimulators **100**. Arrays of stimulators **100** which are denser than transmitter arrays **104** are also useful for avoiding the need for very precise alignment between stimulators **100** and transmitters **104** (with such alignment being beneficial in arrays where there is one transmitter **104** per stimulator **100**), since the web **106** may simply be laid generally over the implanted area and each transmitter **104** may simply send its signal to the closest stimulator(s) **100**. If precise alignment is needed, one or more measures may be used to achieve such alignment. For example, a particular tactile signal pattern could be fed to the transmitters **104** as the user fits the web **106** over the stimulators **100**, with the user then adjusting the web **106** until it provides

a sensation indicating proper alignment; and/or certain stimulators **100** may be colored in certain ways, or the user's skin might be tattooed, to indicate where the boundaries of the web **106** should rest. (Recall that if the stimulators **100** are implanted in the dermis, they will be visible through the translucent epidermis in much the same manner as a tattoo unless they're colored in an appropriate fleshtone.)

The foregoing version of the invention is "passive" in that the stimulators **100**, which are effectively inert structures, are actuated to move by the transmitters **102**. However, other versions of the invention wherein the stimulators include more "active" features are possible, e.g., the stimulators may include features such as mechanical transducers which provide a motion output upon receipt of the appropriate input signal; feedback to the transmitters; onboard processors; and power sources. As in the tactile input system discussed above, these tactile input systems preferably also use wireless communications between implanted stimulators and externally-mounted transmitters. To illustrate, **FIGS. 2** and **3** present a second exemplary version of the invention. Here, a stimulator **200** has an external face **202** which includes a processor **204** (e.g., a CMOS for providing logic and control functions), a photocell **206** (e.g., one or more photodiodes) for receiving a wireless (light) signal from a transmitter, and an optional LED **208** or other output device capable of providing an output signal to the transmitter(s) (not shown) in case such feedback is desired. Light sent by the transmitter(s) to the photocell **206** both powers the processor **204** and conveys a light-encoded control signal for actuation of the stimulator **200**. On the internal face **210** of the stimulator **200**, a diaphragm **212** is situated between the dermis or subcutaneous layer and an enclosed gas chamber **214**, and an actuating electrode **216** is situated across the gas chamber **214** from the diaphragm **212**. Light signals transmitted by the transmitter(s), discussed in greater detail below, are received by the photocell **206**, which charges a capacitor included with the processor **204**, with this charge then being used to electrostatically deflect the diaphragm **212** toward or away from the actuating electrode **216** when activated by the

processor **204**. Since the diaphragm **212** only needs to attain a peak-to-peak motion amplitude of as little as one micrometer, very little power is consumed in its motion. Piezoelectric resistors **218** (**FIG. 3**) situated in a Wheatstone bridge configuration on the diaphragm **212** measure the deformation of the diaphragm **212**, thereby allowing feedback on its degree of displacement, and such feedback can be transmitted back to the transmitter via output device **208** if desired.

The stimulator **200** is preferably scaled such that is has a major dimension of less than 0.5 mm. With appropriate size and configuration, stimulators **200** may be implanted in the manner of a conventional tattoo, with a needle (or array of spaced needles) delivering and depositing each stimulator **200** within the dermis or subcutaneous layer at the desired depth and location. Using state of the art MEMS processing procedures (as of the year 2003), it is projected that the stimulator **200** might be constructed with a size as small as a 200 square micrometer face area (i.e., the area across the external face **202** and internal face **210**), with a depth of approximately 70 micrometers. An exemplary MEMS manufacturing process flow for the stimulator **200** is as follows:

Step	Side of wafer	Comment
2 um CMOS process	Top	More tolerant to defects
Attach handling wafer	Top	
Planarize (CMP)	Bottom	Thin to ~50um
Deposit SiN	Bottom	Insulate lower electrode
Sputter Al	Bottom	Lower electrode
Lithography	Bottom	Electrode and pads for vias
Deposit SiN	Bottom	Insulate lower electrode
Deposit poly	Bottom	~150um
Deposit SiN	Bottom	Mask for cavity
Lithography	Bottom	Pattern hole for cavity
Etch	-	KOH to form cavity (timed)
Deposit poly	Bottom	Seal cavity and strengthen diaphragm

Etch (RIE)	Bottom	Vias; 2 through-hole, 1 stops at lower electrode metal
Fill vias	Bottom	Tungsten
Planarize (CMP)	Bottom	Planarize
Deposit Ti	Bottom	Titanium (bio-compatible)
Lithography	Bottom	Cover only Tungsten, or don't do litho at all if diaphragm is unaffected
Planarize (CMP)	Top	Remove handling wafer
Lithography	Top	Pattern for via to pad interconnect
Deposit Al	Top	Deposit via to pad interconnect
Lithography	Bottom	Pattern for via to pad and via to via interconnect
Deposit Al	Bottom	Deposit via to pad and via to via interconnect

The transmitter (not shown) may take the form of a flexible electro fluorescent display (in which case it may effectively provide only a single transmitter for all stimulators **200**), or it could be formed of an array of LEDs, electro fluorescent displays, or other light sources arrayed across a (preferably flexible) web, as in the transmitter array of **FIG. 1**. The transmitter(s) supply light to power the photocells **206** of the stimulators **200**, with the light bearing encoded information (e.g. frequency and/or amplitude modulated information) which deflects the diaphragms **212** of the stimulators **200** in the desired manner. The light source(s) of the transmitter, as well as the photocells **206** of the stimulator **200**, preferably operate in the visible range since photons in the visible range are more energetic than in other ranges (e.g., the IR or RF ranges), and readily pass through the epidermis for efficient communication with and powering of the stimulators **200** with lower external energy demands.

With appropriate signal tailoring, it is possible to have one transmitter provide distinct communications directed to each of several separate stimulators **200**. For example, if the transmitter delivers a frequency modulated signal which is received by all stimulators **200**, but each stimulator will only respond to a particular frequency or frequency range, each stimulator **200** may provide its own individual response to signals

delivered by a single transmitter. An additional benefit of this scheme is that the aforementioned issue of precise alignment between individual transmitters and corresponding stimulators is reduced, since a single transmitter overlaying all stimulators **200** may effectively communicate with all stimulators **200** without being specifically aligned with any one of them.

As with prior tactile input systems, the tactile input systems of the present invention can be used for sensory substitution or enhancement, e.g., to provide tactile input to supplement or replace visual and/or audible input. As an example of the use of the systems for the substitution or augmentation of the user's visual system, a two dimensional array of stimulators may be implanted at a desired location on the user's body, and an external web or "pack" of one or more transmitters may be placed against the skin at this location. A camera or similar imaging device may then be used to capture visual information (either continuously or discretely, i.e., at times selected by the user), with a signal processor on the web or pack (or elsewhere) converting the visual signal into tactile signals for transmission to the stimulators. Various methods of encoding visual data to obtain tactile stimulation schemes appear in the literature relating to surface tactile displays, and these could be applied with the current invention. The tactile input system could thereby substitute for or augment an impaired visual system (e.g., in the case where the user has partial or complete blindness), or could substitute for or augment unimpaired visual systems as well. For example, the system could provide "rear vision" and/or enhanced peripheral vision to drivers; could use input from an IR ("night vision") system to supplement the user's standard vision in low light conditions; or could use images taken in other non-visible wavelengths to effectively allow a user to "see" outside of normal spectra.

The tactile input systems can similarly be used to substitute for or augment existing audio systems. As an example, the surface of a user's ear canal could be implanted with numerous stimulators, and an appropriate number of transmitters could

be provided in a removable Completely in the Canal (CAC) plug, much like a compact hearing aid, which may be placed in the ear canal to provide power and communications to the stimulators. The plug may house a microphone and processor to sense sound and sort/transform it into individual frequency binned signals which represent the pitch or frequency content of the sound captured by the microphone. Selected stimulators may then be actuated in accordance with the frequency components of the captured sound, in a manner analogous to the process whereby the ear's cochlea provides signals to the brain. As with the exemplary visual-to-tactile input systems discussed above, the audio-to-tactile input systems might supply tactile input for audio inputs outside the ordinary audible range, or might even provide audio-like inputs in response to non-audio signals (e.g., might provide an audio-like tactile input in response to visible or other inputs).

Senses other than vision and hearing can be replaced or augmented as well; for example, a simulated sense of taste could be generated by implementing the tactile input system in conjunction with a device for sensing chemical concentrations in the air, allowing a user to "feel" the concentration of pollutants or hazardous fumes. Alternatively or additionally, the invention can simply be used to compensate for existing tactile impairment, e.g., insensate feet (as might result from complications of diabetes) can be equipped with one or more of pressure and temperature sensors, with the output of these sensors being sent (with or without processing) to one or more transmitters situated adjacent a stimulator array elsewhere on the body. As a result, the user's sense of touch on his/her foot or feet is effectively moved elsewhere on his/her body. This ability to "transport" tactile input to other areas allows, for example, for a prosthetic limb to simulate sensation: sensors in the prosthetic can communicate their signals to one or more transmitters (perhaps located in the socket/fitting of the prosthetic), which in turn communicate with stimulators on the body (perhaps on the stump fit into the socket/fitting).

The description set out above is merely of exemplary preferred versions of the invention, and it is contemplated that numerous additions and modifications can be made. As a first example, in active versions of the invention wherein an actuator is used to deliver motion output to the user, actuators other than (or in addition to) a diaphragm **212** could be used, e.g., a piezoelectric bimorph bending motor, an element formed of an electroactive polymer which changes shape when charged, or some other actuator providing the desired degree of output displacement.

As a second example, while the foregoing tactile input systems are particularly suitable for use with their stimulators imbedded below the epidermis, the stimulators could be implemented externally as well, provided the output motion of the stimulators has sufficient amplitude that it can be felt by a user. To illustrate, the stimulators might be provided on a skullcap, and might communicate with one or more transmitters provided on the interior of a helmet.

As a final example, the foregoing versions of the invention might use other forms of stimulation – e.g., electrical and/or thermal – instead of (or in addition to) mechanical stimulation. Electrical stimulation can simply use electrodes such as those discussed in U.S. Patent 6,430,450 and other references, and thermal stimulators could use resistive heating elements, thermoelectric (Peltier/Thomson) elements, or other heating and/or cooling elements. Greater information might be provided to users by simultaneously delivering different forms of stimulation, e.g., by combining mechanical and thermal stimulation. For example, if pressure and temperature sensors are provided in a prosthetic and their output is delivered to a user via mechanical and thermal stimulators, the prosthetic might more accurately mimic the full range of feeling in the missing appendage. As another example, in a vision substitution system, mechanical inputs might deliver information related to the proximity of objects (in essence delivering the "contour" of the surrounding environment), and electrical stimulation could deliver information regarding color or other characteristics.

The examples described above should not be construed as describing the only possible versions of the invention, and the true scope of the invention will be defined by the claims included in any later-filed utility patent application claiming priority from this provisional patent application.

Claims

What is claimed is:

1. A tactile input system comprising multiple stimulators implanted in the skin of a body below the skin's epidermis in a closely-spaced array, wherein each stimulator or a portion thereof is actuated to deliver at least one of:
   a. mechanical stimulation,
   b. electrical stimulation, and
   c. thermal stimulation,

   upon receipt of a wireless signal.

2. A tactile input system comprising multiple stimulators implanted in the skin of a body below the skin's epidermis in a closely-spaced array, wherein each stimulator or a portion thereof is actuated to move upon receipt of a wireless signal.

3. The tactile input system of claim 1 further comprising one or more transmitters situated atop the epidermis of the body, each transmitter being capable of transmitting a wireless signal to one or more of the stimulators to actuate their movement.

4. The tactile input system of claim 1 wherein each stimulator is separate from the other stimulators, whereby each stimulator lacks any physical connection to any of the other stimulators.

5. The tactile input system of claim 1 wherein each stimulator or a portion thereof is actuated to move upon receipt of a wireless light signal.

6. The tactile input system of claim 1 wherein each stimulator has a volume of less than 10 cubic millimeters.

7. The tactile input system of claim 1 wherein each stimulator includes a movable diaphragm.

8. A tactile input system comprising multiple implantable stimulators wherein each stimulator:

   a. is separate from the other stimulators, whereby each stimulator lacks any direct or indirect physical connection to the other stimulators;
   b. has at least a portion thereof which is movable upon receipt of a wireless signal; and
   c. is less than 10 cubic millimeters in volume.

9. The tactile input system of claim 7 wherein the stimulators are implanted in a closely-spaced array in the skin of a body below the skin's epidermis.

10. A tactile input system comprising:

   a. one or more transmitters outside and adjacent the skin of a body, each transmitter being capable of transmitting a wireless signal into the skin;
   b. one or more stimulators implanted in the skin below the skin's epidermis, wherein each stimulator or a portion thereof moves upon receipt of a wireless signal from one or more of the transmitters.

11. The tactile input system of claim 9 wherein each stimulator has a volume of less than 10 cubic millimeters.

12. The tactile input system of claim 9 wherein each stimulator includes a movable diaphragm.

13. A tactile input system comprising:

a. multiple separate stimulators closely spaced in an array extending across a first area approximating a surface, and wherein at least a portion of each stimulator is movable upon receipt of a wireless signal;

b. one or more transmitters extending across a second area approximating a surface, the second area being at least substantially parallel to the first, each transmitter being capable of transmitting a wireless signal to one or more of the stimulators to actuate their movement.

14. The tactile input system of claim 12 wherein the first area across which the stimulators are arrayed is located beneath the epidermis of a body.

15. The tactile input system of claim 12 wherein each stimulator has a volume of less than 10 cubic millimeters.

16. The tactile input system of claim 12 wherein each stimulator includes a movable diaphragm.

17. A tactile input system comprising:

a. multiple stimulators arrayed across an area approximating a first surface, and wherein at least a portion of each stimulator is movable upon receipt of a wireless signal;

b. multiple transmitters arrayed across a connecting web, the web extending across a second area oriented at least substantially parallel to the first area, each transmitter being capable of transmitting a wireless signal to one or more of the stimulators to actuate their movement.

18. The tactile input system of claim 16 wherein the web is flexible.

19. A tactile input system comprising:

a. multiple implantable stimulators, each bearing no physical connection to the other, wherein at least a portion of each stimulator is movable upon receipt of a wireless signal;

b. multiple transmitters arrayed across a connecting web, wherein each transmitter is capable of transmitting a wireless signal to one or more of the stimulators to actuate their movement.

20. The tactile input system of claim 18 wherein the connecting web is contoured to rest adjacent a portion of a body wherein the stimulators are implanted.

Fig. 1

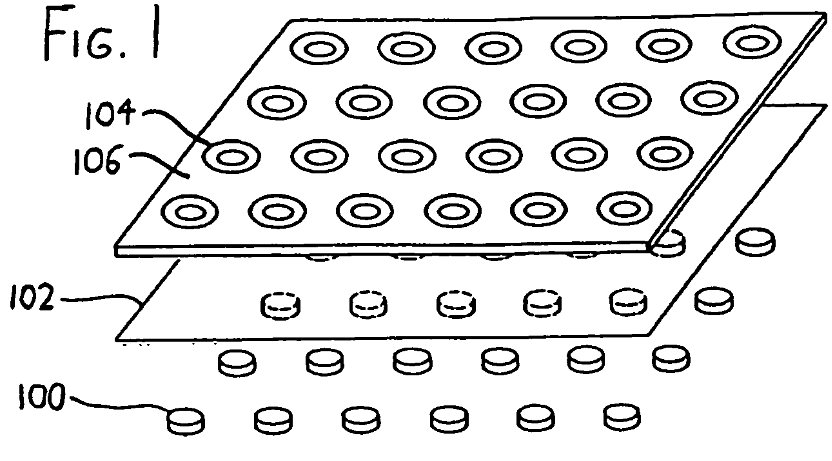


Fig. 2

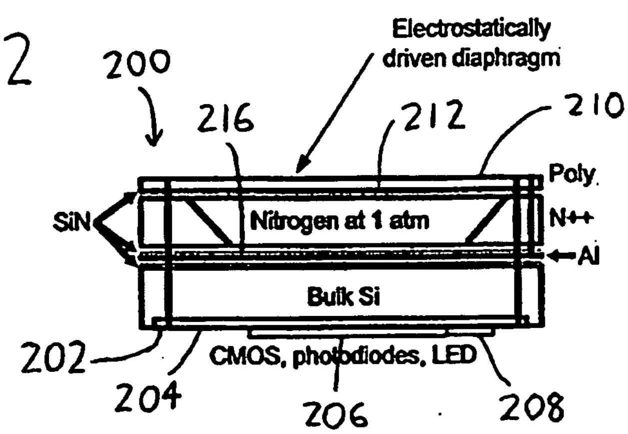
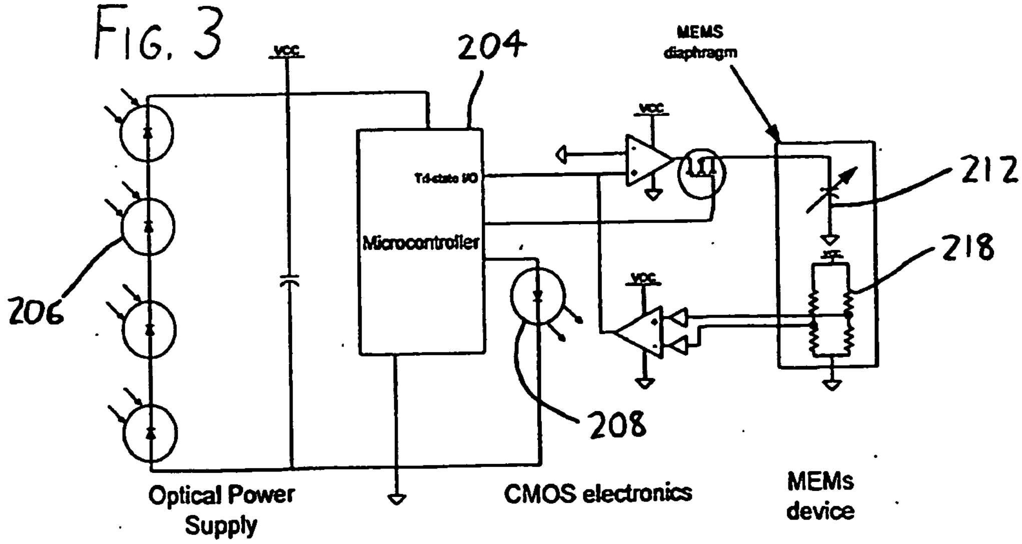


Fig. 3



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